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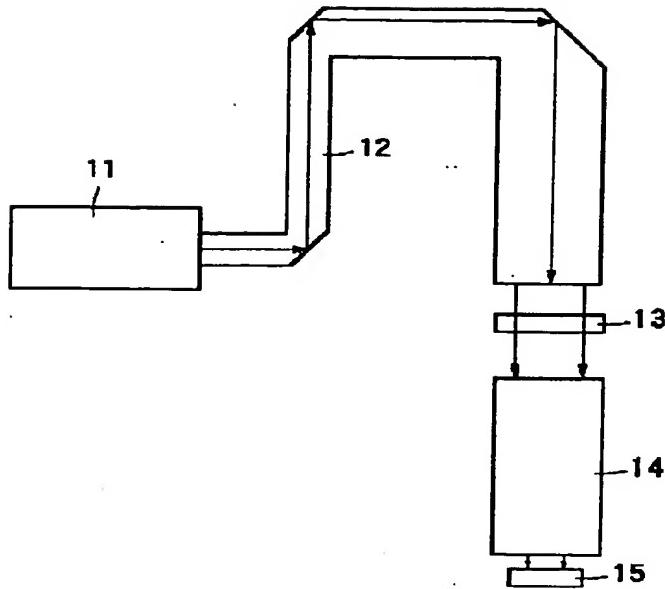
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TITLE : EVALUATION METHOD FOR OPTICAL SYSTEM



ABSTRACT : PROBLEM TO BE SOLVED: To evaluate imaging performance based on separation components by separating wavefront aberration having passed an optical system into a rotational symmetry component around an iris of the optical system and odd/even number symmetry components.

SOLUTION: A light flux emitted from a light source 11 emitting light with a specific wavelength below 400 nm, for example, 248.4 nm passes through an illumination optical system 12 and illuminates a pattern on a mask 13 with a uniform illuminance. The light flux having passed the pattern forms a pattern image on a photosensitive surface on a wafer 15 via a projecting optical system 14 so that the pattern image is transferred on the photosensitive surface. For evaluating the imaging performance of the projecting optical system 14, the wavefront aberration on the imaging wavefront having passed the projection optical system 14 is firstly measured. Then, the wavefront aberration obtained by defining the coordinate system on the emission iris plane of the projection optical system 14 is expressed on the coordinates and expanded to orthogonal functions. For separating the wavefront aberration into the rotational symmetry component around the iris of the optical system and the odd number symmetry component and even number symmetry component, a polar coordinate is used and Zernike's cylindrical functions is also used as an orthogonal function.

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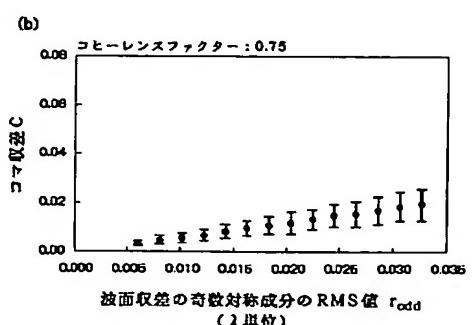
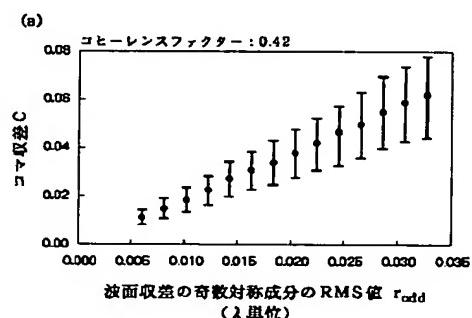
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(54) 【発明の名称】光学系の評価方法

(57) 【要約】

【課題】光学系による波面収差に基づいて、光学系の結像性能をより正確に表現することが出来る評価手法を提供する。

【解決手段】光学系1~4の結像性能を評価する方法において、光学系1~4を通過した波面収差W(ρ, θ)を瞳の中央を中心とする回転対称成分W_{rr}(ρ, θ)と、奇数対称成分W_{odd}(ρ, θ)と、偶数対称成分W_{even}(ρ, θ)に分離し、分離された前記各成分W_{rr}、W_{odd}、W_{even}に基づいて前記光学系の結像性能を評価することを特徴とする。



【特許請求の範囲】

【請求項1】光学系の結像性能を評価する方法において、前記光学系を通過した波面収差を前記光学系の瞳を中心とする回転対称成分と、奇数対称成分と、偶数対称成分に分離し、分離された前記各成分に基づいて前記光学系の結像性能を評価することを特徴とする光学系の評価方法。

【請求項2】前記回転対称成分、奇数対称成分、及び偶数対称成分のそれぞれの自乗平均平方根に基づいて前記光学系の結像性能を評価することを特徴とする請求項1記載の光学系の評価方法。

【請求項3】前記光学系は、400nm以下の特定の波長域で使用される光リソグラフィー用露光装置の投影光学系であることを特徴とする請求項1又は2記載の光学系の評価方法。

【請求項4】投影原版上に形成された所定のパターンの像を感光性基板上へ投影する投影光学系の製造方法において、

投影光学系の波面収差を測定する第1工程と；該第1工程にて測定された前記波面収差を、前記光学系の瞳を中心とする回転対称成分と、奇数対称成分と、偶数対称成分とに分離する第2工程と；該第2工程にて分離された前記各成分に基づいて、前記投影光学系を調整する第3工程と；を有することを特徴とする製造方法。

【請求項5】投影原版上に形成された所定のパターンの像を感光性基板上へ投影露光する投影露光装置において、

請求項4の製造方法により製造された投影光学系を備えることを特徴とする投影露光装置。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、光学系の結像性能の評価方法に関し、特に、光リソグラフィー用露光装置に使用される投影光学系の結像性能の評価方法に関するものである。

【0002】

【従来の技術】LSI等の半導体素子、液晶表示素子、または薄膜磁気ヘッド等を製造するための露光装置では、マスク、レチクルなどの投影原版上のパターンを、投影光学系を介して、ウエハ、ガラスプレートなどの感光性基板上に投影して露光している。投影光学系の形式としては、露光波長の光を透過・屈折するレンズで構成された屈折型の投影光学系、露光波長の光を反射するミラーで構成された反射型の投影光学系、レンズとミラーとを組み合わせた反射屈折型の投影光学系がある。

【0003】近年、半導体素子などの集積度はますます高まり、すなわち基板上に転写されるパターンは微細化の一途をたどっている。そのため、露光装置の投影光学系は、微細なマスクパターンをウエハの感光面上に転写するために、高解像力で無収差に近い、極めて高い光学

性能が要求されている。この要求を満足するためには、投影光学系の設計上の光学性能や、投影光学系を構成するレンズ等の光学部品の内部均質性や研磨精度などの部品精度や、個々の光学部品の組み立て調整の精度などに、非常に高い性能・精度が必要になってきている。それと同時に、組み立てられた投影光学系の現実の結像性能を評価する手法にも、高い精度が必要になってきている。

【0004】投影光学系の結像性能の評価方法については、従来より、ウエハの感光面上に形成されるマスクパターンの空間像を観測して、その空間像に基づいて結像性能を評価する方法や、ウエハの感光面を形成するレジスト上に転写される実際のレジスト像を計測して、そのレジスト像に基づいて結像性能を評価する方法が用いられている。そのほかに、投影光学系を通過した波面収差を計測し、その波面収差の最大値と最小値の差（以下P-V値という）や、自乗平均平方根（以下RMS値という）などを評価指標として、投影光学系の結像性能を評価する方法が用いられており、この場合、P-V値やRMS値が小さいほど優秀な光学系であると考えられてきた。それ故、既存の「高性能」と称する光学系は、これらの値を小さくすることを目的に製造が行われてきた。

【0005】

【発明が解決しようとする課題】しかしながら、波面収差のP-V値やRMS値の小さな投影光学系を完成するには非常に長い工期がかかり、そのため量産化が困難であった。しかもこのようにして製造された投影光学系は、波面収差のP-V値やRMS値が同じである場合にも、空間像や実際のレジスト像を用いた評価では差が生じる場合が少なくない。すなわち従来の波面収差のP-V値やRMS値を用いる評価方法では、所望の光学性能が得られない場合がある。そして、所望の光学性能を達成していない投影光学系によって感光性基板上にマスクパターンを転写しても、より高い集積度を持つ半導体素子等の各種の素子を製造することは困難となる。したがって本発明は、光学系による波面収差に基づいて、光学系の結像性能をより正確に表現することが出来る評価手法を提供することを課題とする。

【0006】

【課題を解決するための手段】本発明は上記課題を解決するためになされたものであり、すなわち、光学系の結像性能を評価する方法において、前記光学系を通過した波面収差を前記光学系の瞳を中心とする回転対称成分と、奇数対称成分と、偶数対称成分に分離し、分離された前記成分に基づいて前記光学系の結像性能を評価することを特徴とする光学系の評価方法である。その際、前記回転対称成分、奇数対称成分、及び偶数対称成分のそれぞれのRMS値（自乗平均平方根）を、前記光学系の結像性能の評価指標とすることが出来る。

【0007】本発明はまた、投影原版上に形成された所

定のパターンの像を感光性基板上へ投影する投影光学系の製造方法において、投影光学系の波面収差を測定する第1工程と；該第1工程にて測定された前記波面収差を、前記光学系の瞳を中心とする回転対称成分と、奇数対称成分と、偶数対称成分とに分離する第2工程と；該第2工程にて分離された前記各成分に基づいて、前記投影光学系を調整する第3工程と；を有することを特徴とする製造方法である。本発明は更に、投影原版上に形成された所定のパターンの像を感光性基板上へ投影露光する投影露光装置において、上記の製造方法により製造された投影光学系を備えることを特徴とする投影露光装置である。

【0008】

【発明の実施の形態】本発明の実施の形態について具体的に説明する。図1は、本発明による評価方法を適用しようとする投影光学系を備えた露光装置を示す。400nm以下の特定の波長、例えば248.4nmの波長の光を発する光源11より発した光束は、照明光学系12を通過し、マスク13上のパターンPを均一な照度にて照明する。パターンPを通過した光束は、投影光学系14を介して、ウェハ15上の感光面にパターンPの像を形成し、こうしてパターンPの像がウェハ15上の感光面に転写される。

【0009】投影光学系14の結像性能を評価するには、先ず、投影光学系14を通過した結像波面の波面収差を測定する。波面収差の測定には、フィゾー型干渉計、トワイマングリーン型干渉計、シアリング型干渉計などが用いられる。一例として、図2にフィゾー型干渉計を示す。光源21から射出した光束は、ハーフプリズム22で反射（又は透過）して、フィゾーレンズ23に入射する。フィゾーレンズ23に入射した光束のうち、一部の光束はフィゾーレンズの参照面23aで反射して参照光となり、往路を逆進してハーフプリズム22に戻る。フィゾーレンズ23に入射した光束のうち、他の光束は参照面23aを透過して測定光となる。測定光は、

$$\begin{array}{llll}
 n : Z_n(\rho, \theta) & & & \\
 0 : 1 & 1 : \rho \cos \theta & 2 : \rho \sin \theta & 3 : 2\rho^2 - \\
 1 & 4 : \rho^2 \cos 2\theta & 5 : \rho^2 \sin 2\theta & 6 : (3\rho^2 - 2) \\
 \rho \cos \theta & 7 : (3\rho^2 - 2) \rho \sin \theta & 8 : 6\rho^4 - 6\rho^2 + 1 & \\
 9 : \rho^3 \cos 3\theta & 10 : \rho^3 \sin 3\theta & 11 : (4\rho^2 - 3) \rho^2 \cos 2 & \\
 \theta & 12 : (4\rho^2 - 3) \rho^2 \sin 2\theta & 13 : (10\rho^4 - 12\rho^2 + 3) & \\
) \rho \cos \theta & 14 : (10\rho^4 - 12\rho^2 + 3) \rho \sin \theta & 15 : 20\rho^6 & \\
 - 30\rho^4 + 12\rho^2 - 1 & 16 : \rho^4 \cos 4\theta & 17 : \rho^4 \sin 4\theta & \\
 18 : (5\rho^2 - 4) \rho^3 \cos 3\theta & 19 : (5\rho^2 - 4) \rho^3 \sin 3\theta & & \\
 20 : (15\rho^4 - 20\rho^2 + 6) \rho^2 \cos 2\theta & 21 : (15\rho^4 - 20\rho^2 + 6) & & \\
) \rho^2 \sin 2\theta & 22 : (35\rho^6 - 60\rho^4 + 30\rho^2 - 4) \rho \cos \theta & & \\
 23 : (35\rho^6 - 60\rho^4 + 30\rho^2 - 4) \rho \sin \theta & 24 : 70\rho^8 - 140 & & \\
 \rho^6 + 90\rho^4 - 20\rho^2 + 1 & 25 : \rho^5 \cos 5\theta & 26 : \rho^5 \sin 5\theta & \\
 27 : (6\rho^2 - 5) \rho^4 \cos 4\theta & 28 : (6\rho^2 - 5) \rho^4 \sin 4\theta & & \\
 29 : (21\rho^4 - 30\rho^2 + 10) \rho^3 \cos 3\theta & 30 : (21\rho^4 - 30\rho^2 + 10) \rho^3 \sin 3\theta & &
 \end{array}$$

投影光学系14を通過し、XYステージ25上に載置された球面鏡24で反射し、往路を逆進してハーフプリズム22に戻る。ハーフプリズム22に入射した参照光と測定光は、ハーフプリズム22を透過（又は反射）して、撮像素子26上に球面鏡24の像を形成する。

【0010】投影光学系14に収差がないときには、測定光は球面鏡24の各点に同位相で入射し、フィゾーレンズの参照面23aの各点に同位相で戻る。したがって撮像素子26上の各点で参照光と測定光との位相差が等しいから、球面鏡24の像は均一な強度分布となる。しかし、投影光学系14に収差があるときには、撮像素子26上の各点で参照光と測定光との位相差が異なるから、球面鏡24の像として干渉縞が観測される。測定光は投影光学系14を2回通過しているから、干渉縞の位相差を2で割ることにより、投影光学系14の波面収差Wを求めることが出来る。

【0011】次いで、投影光学系14の射出瞳面上に座標系を定めて、得られた波面収差Wをその座標系で表わし、更に、直交関数系に展開する。本発明では、波面収差Wを前記光学系の瞳を中心とする回転対称成分と、奇数対称成分と、偶数対称成分に分離するから、座標系としては極座標を用い、直交関数系としてはツェルニケの円筒関数を用いる。

【0012】すなわち、射出瞳面上に極座標を定め、得られた波面収差Wを、

$$W(\rho, \theta)$$

として表わす。ここで ρ は射出瞳の半径を1に規格化した規格化瞳半径、 θ は極座標の動径角である。次いで、波面収差 $W(\rho, \theta)$ を、ツェルニケの円筒関数系 $Z_n(\rho, \theta)$ を用いて、

$$W(\rho, \theta) = \sum C_n Z_n(\rho, \theta) \quad \dots (1)$$

と展開する。ここで C_n は展開係数である。また、ツェルニケの円筒関数系 $Z_n(\rho, \theta)$ のうち、 $n=0 \sim 3$ は次の通りである。

【0013】

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$$\begin{aligned}
 & + 10) \rho^3 \sin 3\theta \quad 31: (56\rho^6 - 104\rho^4 + 60\rho^2 - 10) \rho^2 c \\
 & \cos 2\theta \quad 32: (56\rho^6 - 104\rho^4 + 60\rho^2 - 10) \rho^2 \sin 2\theta \\
 & 33: (126\rho^8 - 280\rho^6 + 210\rho^4 - 60\rho^2 + 5) \rho \cos \theta \quad 34: \\
 & (126\rho^8 - 280\rho^6 + 210\rho^4 - 60\rho^2 + 5) \rho \sin \theta \quad 35: 25 \\
 & 2\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1
 \end{aligned}$$

【0014】既に述べたように、従来の波面収差Wに基づく評価手法は、波面収差Wの最大最小の差(P-V値)やRMS値を評価指標として用いていた。しかしながら、P-V値やRMS値による評価では同じ値となる場合でも、各項の展開係数C₀、C₁、C₂、……の組み合わせによっては、空間像やレジスト像による評価では異なる性能を示す場合があった。すなわち波面収差WのP-V値やRMS値は、空間像やレジスト像による評価を必ずしも正確に予測するものではなかった。

【0015】そこで本発明者は、(1)式の各項を、(a) θを含まない項、すなわち、ある座標での値と、その座標を瞳の中央を中心として任意の角度だけ回転した座標での値とが等しい回転対称な成分

(b) sin(又はcos)θ、sin(又はcos)3θなどの、

$$\begin{aligned}
 & W_{r..}(\rho, \theta) \\
 & = C_0 + C_3 (2\rho^2 - 1) + C_6 (6\rho^4 - 6\rho^2 + 1) \\
 & + C_{15} (20\rho^6 - 30\rho^4 + 12\rho^2 - 1) \\
 & + C_{24} (70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1) + \dots
 \end{aligned} \quad \dots (2)$$

$$\begin{aligned}
 & W_{o..}(\rho, \theta) \\
 & = C_1 (\rho \cos \theta) + C_2 (\rho \sin \theta) + C_6 ((3\rho^2 - 2) \rho \cos \theta) \\
 & + C_7 ((3\rho^2 - 2) \rho \sin \theta) + C_9 (\rho^3 \cos 3\theta) \\
 & + C_{10} (\rho^3 \sin 3\theta) + \dots
 \end{aligned} \quad \dots (3)$$

$$\begin{aligned}
 & W_{e..}(\rho, \theta) \\
 & = C_4 (\rho^2 \cos 2\theta) + C_5 (\rho^2 \sin 2\theta) \\
 & + C_{11} ((4\rho^2 - 3) \rho^2 \cos 2\theta) \\
 & + C_{12} ((4\rho^2 - 3) \rho^2 \sin 2\theta) + C_{16} (\rho^4 \cos 4\theta) \\
 & + C_{17} (\rho^4 \sin 4\theta) + \dots
 \end{aligned} \quad \dots (4)$$

となる。

【0017】(1)式の波面収差Wの自乗平均平方根(RMS値)をr_{r..}とし、(2)式の波面収差の回転対称成分W_{r..}のRMS値をr_{o..}とし、(3)式の波面収差の奇数対称成分W_{o..}のRMS値をr_{e..}とし、(4)式の波面収差の偶数対称成分W_{e..}のRMS値をr_{e..}とすると、これらの間には、

$$(r_r)^2 = (r_{r..})^2 + (r_{o..})^2 + (r_{e..})^2$$

の関係がある。

【0018】r_{r..}が球面収差と相関があることは自明であるが、本発明者は、r_{o..}をコマ収差と関連付け、r_{e..}を非点収差と関連付けて検討したところ、共に強い相関があることがわかった。したがってこれら3つのRMS値r_{r..}、r_{o..}、r_{e..}を投影光学系の評価指標として用いることにより、投影光学系によって形成され

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動径角θの奇数倍の3角関数を含む項、すなわち、ある座標での値と、その座標を瞳の中央を中心として360°の奇数分の1だけ回転した座標での値とが等しい奇数対称な成分

10 (c) sin(又はcos)2θ、sin(又はcos)4θなどの、動径角θの偶数倍の3角関数を含む項、すなわち、ある座標での値と、その座標を瞳の中央を中心として360°の偶数分の1だけ回転した座標での値とが等しい偶数対称な成分に分類して検討した。

【0016】すなわち、波面収差Wの回転対称成分、奇数対称成分、及び偶数対称成分をそれぞれ、W_{r..}、W_{o..}、W_{e..}とすると、

.... (3)

.... (4)

る実際の空間像やレジスト像の球面収差、コマ収差、非点収差と関連付けることができ、より合理的に投影光学系の設計、調整が可能となった。

【0019】【実施例1】次に実施例1と実施例2によって、具体的な評価の例を示す。実施例1では、波面収差の奇数対称成分のRMS値r_{o..}と、コマ収差との関係を示す。まず、コマ収差の定量化について説明する。空間像やレジスト像を使ったコマ収差の検出法には、古くから様々な方法が知られている。コマ収差が発生すると像の横ずれが起こるが、この横ずれの量は物体構造や空間周波数によって異なり、横ずれ量の差からコマ収差を定量化することができる。図3にコマ収差を検出するための物体構造(マスクパターン)の例を示す。幅Lの5本の遮光パターンを間隔Sで配置する。通常は、間隔Sは線幅Lと

同じ寸法であることが多い。間隔Sと線幅L_sとが等しいときには、幅L (=S) の線が間隔Sにて無限に並んでいる細かい物体（空間周波数の高い物体）と、幅9Sの1つの大きな物体（空間周波数の低い物体）の両方の性質を併せ持つ。

【0020】次に、投影光学系の調整手法の一例について説明する。投影光学系において波面収差の回転対称成分が存在する場合、投影光学系を構成している複数の光学部材同士の間隔のうち、少なくとも1つの間隔を変化させることによって波面収差の回転対称成分を補正することができる。また、投影光学系において波面収差の奇数対称成分が存在している場合、この奇数対称成分とコマ収差との間で強い相関があり、単純な内コマ、外コマであるときには投影光学系中の複数の光学部材の間隔のうち、少なくとも1つの間隔を変化させることにより、内コマ、外コマを補正することができる。また、偏心コマ（光学部材が光軸に対して偏心または傾くことによるコマ収差）であるときには、投影光学系中の複数の光学部材のうち、少なくとも1つの光学部材を光軸に対して直交方向へ移動させるか、傾けることにより、この偏心コマを補正できる。

【0021】また、投影光学系において波面収差の偶数対称成分が存在している場合、この偶数対称成分と非点収差との間で強い相関があり、単純な像面湾曲による非点収差であるときには、投影光学系中の複数の光学部材の間隔のうち、少なくとも1つの間隔を変化させること

光学系のNA（開口数）	0. 60
波長λ	248. 4 nm
投影光学系の倍率	0. 2倍
物体寸法L	1. 0 μm
データ数	500個 (中央の線の像の幅L _s = 0. 2 μm)

【0024】図5（a）と（b）に、波面収差の奇数対称成分のRMS値r_{odd}と、コマ収差Cとの関係を示す。このうち同図（a）は、コヒーレンスファクター（照明光学系と投影光学系のNAの比率）が0. 42の場合であり、同図（b）は、コヒーレンスファクターが0. 75の場合である。また縦軸のエラーバーは、平均値±1σを表す。同図より明らかなように、投影光学系の波面収差のうちの奇数対称成分W_{odd}の波面収差のRMS値r_{odd}が、コマ収差と強い相関を持っていることが確認できた。

光学系のNA（開口数）	0. 60
波長λ	248. 4 nm
投影光学系の倍率	0. 2倍
物体形状	L = S = 1. 0 μmの無限周期パターン
データ数	500個

【0026】図5（a）と（b）に、波面収差の偶数対称成分のRMS値r_{even}と、非点収差との関係を示す。このうち同図（a）は、コヒーレンスファクターが0.

により補正できる。また、投影光学系の像面上の中心での非点収差（軸上非点収差）であるときには、投影光学系中の複数の光学部材のうち、少なくとも1つの光学部材を光軸を中心として回転させることにより補正できる。

【0022】図4（a）と（b）に、この物体を投影光学系で結像させた場合の像面上の光強度分布を示す。このうち同図（a）は、コマ収差がない場合の光強度分布を示し、同図（b）は、コマ収差がある場合の光強度分布を示す。5本の線の像のうち、中央の線の像の光強度幅L_sが、ちょうどL×m（mは光学系の倍率）になる光強度でスライスして、このときの5本の線の左端の線の像の光強度幅をL_lとし、右端の線の像の光強度幅をL_rと定義すると、空間周波数によってコマ収差による横ずれ量に差があるので、L_lとL_rの寸法に差が生じる。そこで、たとえばコマ収差Cを、
 $C \equiv (L_l - L_r) / (L_l + L_r)$

と定義することにより、光強度分布を利用してコマ収差量の定量化が可能となる。

【0023】さて本発明者は、（3）式の波面収差の奇数対称成分W_{odd}の展開係数C₁、C₂、C₃、…がさまざまな値を持ったケースをモンテカルロ法によって模擬し、各々のケースにおける波面収差の奇数対称成分のRMS値r_{odd}とコマ収差Cを計算した。計算条件は以下の通りである。

【0025】
 【実施例2】次に実施例2では、波面収差の偶数対称成分のRMS値r_{even}と、非点収差との関係を示す。実施例1と同様に、本発明者は、（4）式の波面収差の偶数対称成分W_{even}の展開係数C₁、C₂、C₃、…がさまざまな値を持ったケースをモンテカルロ法によって模擬し、各々のケースにおける波面収差の偶数対称成分のRMS値r_{even}と非点収差を計算した。計算条件は以下の通りである。

40

42の場合であり、同図（b）は、コヒーレンスファクターが0. 75の場合である。また縦軸のエラーバーは、平均値±1σを表す。同図より明らかなように、投

影光学系の波面収差のうちの偶数対称成分 W_{even} の波面収差のRMS値 r_{even} が、非点収差と強い相関を持っていることが確認できた。なお、以上の説明では、結像性能を評価しようとする光学系が、露光装置の投影光学系である場合について説明したが、本発明による評価方法は明らかに、いかなる種類の結像光学系に対しても適用することが出来る。

【0027】

【発明の効果】以上のように本発明によって、光学系を透過した波面収差を瞳の中央を中心とした回転対称成分、奇数対称成分、偶数対称成分に分離して評価を行うことにより、光学系によって形成される実際の空間像やレジスト像の球面収差、コマ収差、非点収差と関連付けることができ、より合理的に光学系の設計、調整が可能となった。

【図面の簡単な説明】

【図1】半導体素子等の製造に使用される露光装置の概略図

【図2】フィゾー型干渉計の波面収差測定の概念図

【図3】コマ収差を検出するための物体構造（マスクパターン）の一例を示す図

【図4】(a) 図3の物体をコマ収差がない光学系で結像させた場合の像面上の光強度分布と、(b) 同じくコマ収差がある光学系で結像させた場合の像面上の光強度分布を示す図

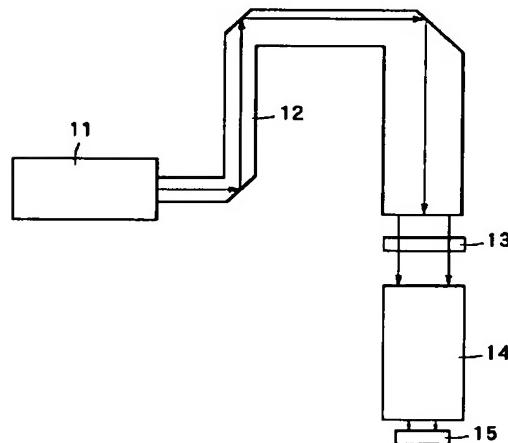
【図5】(a) コヒーレンスファクターが0.42の場合と、(b) コヒーレンスファクターが0.75の場合の、波面収差の奇数対称成分のRMS値 r_{odd} とコマ収差Cとの関係を示す図

【図6】(a) コヒーレンスファクターが0.42の場合と、(b) コヒーレンスファクターが0.75の場合の、波面収差の偶数対称成分のRMS値 r_{even} と非点収差との関係を示す図

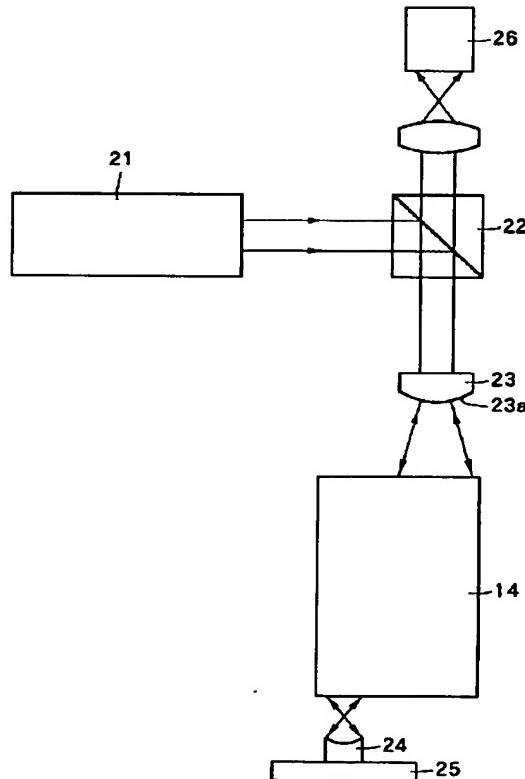
【符号の説明】

1 1 …光源	1 2 …照明光学系
1 3 …マスク	1 4 …投影光学系
1 5 …ウエハ	2 1 …光源
2 2 …ハーフプリズム	2 3 …フィゾーレンズ
2 3 a …参照面	2 4 …球面鏡
2 5 …XYステージ	2 6 …撮像素子
P …パターン	

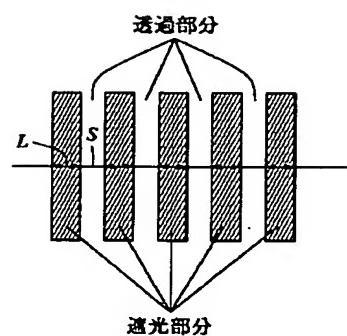
【図1】



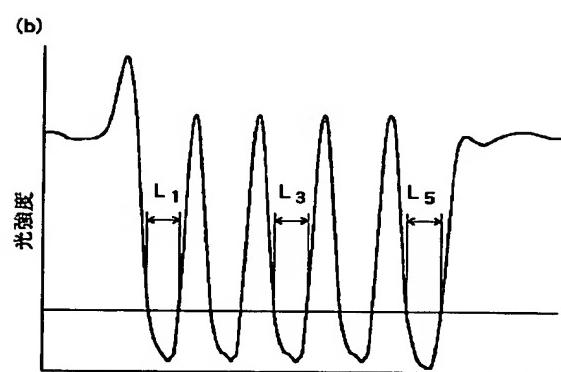
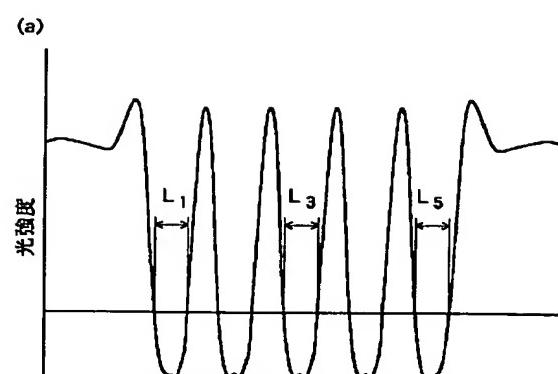
【図2】



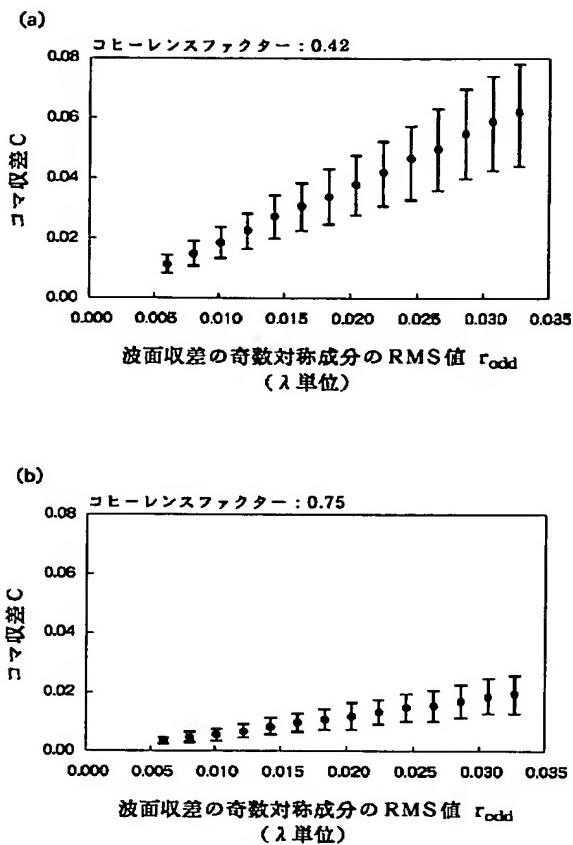
【図3】



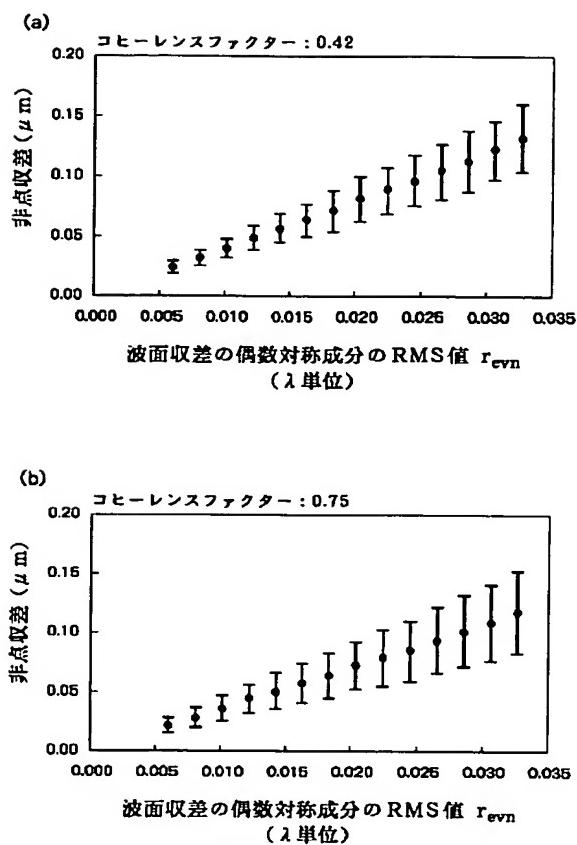
【図4】



【図 5】



【図 6】



Japanese Patent Application Laid-open No. 2000-121491

[Title of the Invention]

Evaluating Method of Optical System

5

[Abstract]

[Object] To provide an evaluating method for indicating image forming quality of an optical system with higher accuracy based on wavefront aberration of the optical system.

10

[Solution] In a method of evaluating the image forming quality of an optical system 14, wavefront aberration $W(\rho, \theta)$ having passed through the optical system 14 is divided into a rotational symmetry component $W_{rot}(\rho, \theta)$ around a center of a pupil, an odd symmetry component $W_{odd}(\rho, \theta)$ and an even symmetry component $W_{even}(\rho, \theta)$, and the image forming quality of the optical system is evaluated based on the respective components W_{rot} , W_{odd} and W_{even} .

15

[What is Claimed is]

[Claim 1] A method of evaluating image forming quality of an optical system, wherein wavefront aberration having passed through said optical system is divided into a rotational symmetry component around a center of a pupil of said optical system, an odd symmetry component and an even symmetry component, and the image forming quality of said optical system is evaluated based on said respective divided components.

[**Claim 2**] The method according to Claim 1, wherein the image forming quality of said optical system is evaluated based on a root-mean-square value of each of said rotational symmetry component, said odd symmetry component and said even symmetry component.

[**Claim 3**] The method according to one of Claims 1 and 2, wherein said optical system is a projection optical system of an exposure apparatus for optical lithography used in a specific wavelength range not more than 400nm.

10 [**Claim 4**] A making method of a projection optical system which projects an image of a predetermined pattern formed on a projection original plate onto a photosensitive substrate, comprising:

a first process of measuring wavefront aberration of
15 a projection optical system;

 a second process of dividing said wavefront aberration measured in the first process into a rotational symmetry component around a center of a pupil of said projection optical system, an odd symmetry component and an even symmetry component; and

 a third process of adjusting said projection optical system based on said respective components divided in the second process.

[**Claim 5**] A projection exposure apparatus which projects and transfers an image of a predetermined pattern formed on a projection original plate onto a photosensitive substrate, comprising:

 a projection optical system made in the method

according to Claim 4.

[Detailed Description of the Invention]

[0001]

5 **[Technical Field to Which the Invention Pertains]**

The present invention is related to a method of evaluating image forming quality of an optical system, and more particularly, to a method of evaluating the image forming quality of a projection optical system used in an exposure apparatus for optical lithography.

[0002]

[Prior Art]

In an exposure apparatus for producing semiconductor devices such as LSI, liquid crystal display devices, thin magnetic head and like, a pattern on a projection original plate such as a mask or a reticle is projected and transferred onto a photosensitive substrate such as a wafer or a glass plate. As the types of projection optical systems, there are a refraction projection optical system made up of lenses which light having exposure wavelength passes through and is refracted, a reflection projection optical system made up of mirrors which reflects the light having exposure wavelength, and a catadioptric projection optical system made up of lenses and mirrors in combination.

[0003] In recent years, integration levels of the semiconductor devices have become increasingly higher, and a size of a pattern transferred onto a substrate has

become even finer. Therefore, in order to transfer a fine mask pattern onto a photosensitive surface of a wafer, extremely high optical properties with high resolution and almost no aberration are required for a projection
5 optical system of an exposure apparatus. To satisfy such requirements, remarkably high quality and accuracy are needed for the optical properties in design of the projection optical system, the accuracy of components such as internal homogeneity and grinding accuracy of
10 optical components such as lenses structuring the projection optical system, and the adjustment accuracy in assembling respective optical components. Simultaneously, high accuracy is also required for a method of evaluating the actual image forming quality of the assembled
15 projection optical system.

[0004] As methods of evaluating the image forming quality of a projection optical system, a method in which an aerial image of a mask pattern formed on a photosensitive surface of a wafer is observed, and the image forming
20 quality is evaluated based on the aerial image, and a method in which an actual resist image transferred onto a resist forming a photosensitive surface of a wafer is measured and the image forming quality is evaluated based on the resist image have been used. In addition, a method
25 has been used in which the wavefront aberration having passed through the projection optical system is measured, and the image forming quality is evaluated using a difference between a maximum value and a minimum value of

the wavefront aberration (hereinafter referred to as a "P-V value") and a root-mean-square value (hereinafter referred to as a "RMS value") as evaluation indexes. In
this case, it has been thought that the smaller a P-V
5 value or a RMS value is, the more superior an optical system is. Therefore, conventional optical systems being regarded as having "high quality" have been manufactured for the purpose of decreasing these values.

[0005]

10 **[Problems to Be Solved by the Invention]**

However, it took a long period of time to complete a projection optical system with a small P-V value and/or RMS value of the wavefront aberration, and for the reason its mass production was difficult. Further, with the
15 projection optical system manufactured in such method, it is not rare that the evaluation using an aerial image or an actual resist image shows differences even when the P-V value or the RMS value of the wavefront aberration is same. In other words, desirable optical properties cannot
be obtained at times in the conventional evaluating
20 method using the P-V value or the RMS value. And, when a mask pattern is transferred onto a photosensitive substrate by a projection optical system which does not attain the desirable optical properties, it is difficult
25 to manufacture various types of devices such as semiconductor devices with higher integration levels.
Accordingly, the object of the present invention is to provide an evaluating method for indicating the image

forming quality of an optical system more accurately.

[0006]

[Means to Solve the Problems] The present invention is made to solve the above problems, and more particularly, 5 according to the present invention, there is provided a method of evaluating image forming quality of an optical system, wherein wavefront aberration having passed through the optical system is divided into a rotational symmetry component around a center of a pupil of the 10 optical system, an odd symmetry component and an even symmetry component, and the image forming quality of said optical system is evaluated based on the divided components. When evaluating, a RMS value (root-mean-square value) of each of the rotational symmetry 15 component, the odd symmetry component and the even symmetry component may be used as evaluation indexes of the image forming quality of the optical system.

[0007] Further, according to the present invention, there is provided a making method of a projection optical 20 system which projects an image of a predetermined pattern formed on a projection original plate onto a photosensitive substrate, comprising: a first process of measuring the wavefront aberration of the projection optical system; a second process of dividing the 25 wavefront aberration measured in the first process into a rotational symmetry component around a center of a pupil of the optical system, an odd symmetry component and an even symmetry component; and a third process of adjusting

the projection optical system based on the respective components divided in the second process. Further, according to the present invention, there is provided a projection exposure apparatus which projects and

5 transfers an image of a predetermined pattern formed on a projection original plate onto a photosensitive substrate, comprising a projection optical system made in the above-described method.

[0008]

10 **[Preferred Embodiment of the Invention]** The embodiments of the present invention will be described in detail. Fig. 1 illustrates an exposure apparatus comprising a projection optical system to which an evaluating method of the present invention is to be applied. A beam having 15 a specific wavelength not more than 400nm, for example, a wavelength of 248.4nm emitted from a light source 11 passes through an illumination optical system 12, and illuminates a pattern P on a mask 13 with uniform illuminance. The beam having passed through the pattern P 20 forms an image of the pattern P on a photosensitive surface of a wafer 15 via a projection optical system 14, and thereby the image of the pattern P is transferred onto the photosensitive surface on the wafer 15.

[0009] In order to evaluate image forming quality of the 25 projection optical system 14, first, wavefront aberration of the image forming wavefront having passed through the projection optical system 14 is measured. For the measurement of the wavefront aberration, Fizeau

interferometer, Twyman-Green interferometer, Shearing interferometer or the like is used. As an example, Fizeau interferometer is shown in Fig. 2. A beam emitted from a light source 21 is reflected off (or passes through) a
5 half prism 22 and is incident on a Fizeau lens 23. One part of the beam incident on the Fizeau lens 23 is reflected off a reference plane 23a of the Fizeau lens and becomes a reference beam, which returns to the half prism 22 by going backward through an approach route. The
10 other part of the beam incident on the Fizeau lens 23 passes through the reference plane 23a and becomes a measurement beam. The measurement beam passes through the projection optical system 14, and then is reflected off a spherical mirror 24 placed on a XY stage 25 and returns
15 to the half prism 22 by going backward through an approach route. The reference beam and the measurement beam incident on the half prism 22 pass through (or are reflected off) the half prism 22 and form an image of the spherical mirror 24 on an image pickup device 26.
20 [0010] When there is no aberration in the projection optical system 14, the measurement beam is incident on each point of the spherical mirror 24 in the same phase and returns to each point of the reference plane 23a of the Fizeau lens in the same phase. Therefore, since a
25 phase difference between the reference beam and the measurement beam is same at each point on the image pickup device 26, an image of the spherical mirror 24 has a uniform intensity distribution. Meanwhile, when there

are aberrations in the projection optical system 14, because the phase difference between the reference beam and the measurement beam is different at each point on the image pickup device 26, interference bands are

5 observed as the image of the spherical mirror 24. Since the measurement beam has passed through the projection optical system 14 twice, wavefront aberration W of the projection optical system 14 can be obtained by dividing the phase difference of the interference bands by two.

10 [0011] Next, a coordinate system is set on an exit pupil plane of the projection optical system 14. Then, the obtained wavefront aberration W is indicated using the coordinate system, and further is expanded in an orthogonal function system. In the present invention,

15 since the wavefront aberration W is divided into the rotational symmetry component around the center of the pupil of the optical system, the odd symmetry component and the even symmetry component, a polar coordinate is used as the coordinate system and a Zernike's cylindrical function as the orthogonal function system.

20 [0012] The polar coordinate is set on the exit pupil plane, and the obtained wavefront aberration W is denoted as $W(\rho, \theta)$. In this case, ρ is a standardized pupil radius that a radius of an exit pupil is standardized to be 1, and θ is a radial angle of the polar coordinate.

25 Next, the wavefront aberration $W(\rho, \theta)$ is expanded in the equation (1) using a Zernike's cylindrical function system $Z_n(\rho, \theta)$ as follows:

$$W(\rho, \theta) = \sum C_n Z_n(\rho, \theta) \dots \quad (1)$$

In the above equation, C_n is an expanded coefficient.

Further, $n=0$ to 35 in the Zernike's cylindrical function system $Z_n(\rho, \theta)$ is as follows.

5 [0013]

- n: $Z_n(\rho, \theta)$
- 0: 1
- 1: $\rho \cos \theta$
- 2: $\rho \sin \theta$
- 10 3: $2\rho^2 - 1$
- 4: $\rho^2 \cos 2\theta$
- 5: $\rho^2 \sin 2\theta$
- 6: $(3\rho^2 - 2)\rho \cos \theta$
- 7: $(3\rho^2 - 2)\rho \sin \theta$
- 15 8: $6\rho^4 - 6\rho^2 + 1$
- 9: $\rho^3 \cos 3\theta$
- 10: $\rho^3 \sin 3\theta$
- 11: $(4\rho^2 - 3)\rho^2 \cos 2\theta$
- 12: $(4\rho^2 - 3)\rho^2 \sin 2\theta$
- 20 13: $(10\rho^4 - 12\rho^2 + 3)\rho \cos \theta$
- 14: $(10\rho^4 - 12\rho^2 + 3)\rho \sin \theta$
- 15: $20\rho^6 - 30\rho^4 + 12\rho^2 - 1$
- 16: $\rho^4 \cos 4\theta$
- 17: $\rho^4 \sin 4\theta$
- 25 18: $(5\rho^2 - 4)\rho^3 \cos 3\theta$
- 19: $(5\rho^2 - 4)\rho^3 \sin 3\theta$
- 20: $(15\rho^4 - 20\rho^2 + 6)\rho^2 \cos 2\theta$
- 21: $(15\rho^4 - 20\rho^2 + 6)\rho^2 \sin 2\theta$

- 22: $(35\rho^6 - 60\rho^4 + 30\rho^2 - 4)\rho\cos\theta$
 23: $(35\rho^6 - 60\rho^4 + 30\rho^2 - 4)\rho\sin\theta$
 24: $70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$
 25: $\rho^5\cos 5\theta$
 5 26: $\rho^5\sin 5\theta$
 27: $(6\rho^2 - 5)\rho^4\cos 4\theta$
 28: $(6\rho^2 - 5)\rho^4\sin 4\theta$
 29: $(21\rho^4 - 30\rho^2 + 10)\rho^3\cos 3\theta$
 30: $(21\rho^4 - 30\rho^2 + 10)\rho^3\sin 3\theta$
 10 31: $(56\rho^6 - 104\rho^4 + 60\rho^2 - 10)\rho^2\cos 2\theta$
 32: $(56\rho^6 - 104\rho^4 + 60\rho^2 - 10)\rho^2\sin 2\theta$
 33: $(126\rho^8 - 280\rho^6 + 210\rho^4 - 60\rho^2 + 5)\rho\cos\theta$
 34: $(126\rho^8 - 280\rho^6 + 210\rho^4 - 60\rho^2 + 5)\rho\sin\theta$
 35: $252\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$

15

[0014] As is described above, in the conventional evaluating method based on the wavefront aberration W , a difference between the maximum and minimum of the wavefront aberration W (a P-V value) and a RMS value are 20 used as evaluation indexes. However, even when the evaluation using the P-V value and the RMS value shows the same value, sometimes the evaluation using an aerial image or a resist image shows different optical properties depending on the combination of the expanded 25 coefficients $C_0, C_1, C_2 \dots$ of each term. Thus, the evaluation using the aerial image or the resist image is not always accurately predicted by the P-V value and the RMS value of the wavefront aberration W .

[0015] Therefore, the inventors of the present invention have divided the terms of the equation (1) into the following components and have researched them:

- (a) a term not including θ : a rotational symmetry component in which a value at one coordinate and a value at the other coordinate obtained by rotating the one coordinate around a center of a pupil an arbitrary angle are equal,
- (b) a term including a trigonometric function of oddly multiplied radial angle θ such as \sin (or \cos) θ , \sin (or \cos) 3θ : an odd symmetry component in which a value at one coordinate and a value at the other coordinate obtained by rotating the one coordinate around a center of a pupil an angle of oddly dividing 360 degree are equal, and
- (c) a term including a trigonometric function of evenly multiplied radial angle θ such as \sin (or \cos) 2θ , \sin (or \cos) 4θ : an even symmetry component in which a value at one coordinate and a value at the other coordinate obtained by rotating the one coordinate around a center of a pupil an angle of evenly dividing 360 degree are equal.

[0016] When the rotational symmetry component, the odd symmetry component and the even symmetry component of the wavefront aberration W are denoted as W_{rot} , W_{odd} , W_{even} , the equations are as follows:

$$\begin{aligned} W_{rot} (\rho, \theta) \\ = & C_0 + C_3(2\rho^2 - 1) + C_8(6\rho^4 - 6\rho^2 + 1) \\ & + C_{15}(20\rho^6 - 30\rho^4 + 12\rho^2 - 1) \end{aligned}$$

$$\begin{aligned}
 & + C_{24}(70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1) + \dots \\
 & \dots \quad (2)
 \end{aligned}$$

$$\begin{aligned}
 W_{\text{odd}}(\rho, \theta) \\
 = & C_1(\rho \cos \theta) + C_2(\rho \sin \theta) + C_6((3\rho^2 - 2)\rho \cos \theta) \\
 5 & + C_7((3\rho^2 - 2)\rho \sin \theta) + C_9(\rho^3 \cos 3\theta) \\
 & + C_{10}(\rho^3 \sin 3\theta) + \dots \\
 & \dots \quad (3)
 \end{aligned}$$

$$\begin{aligned}
 W_{\text{even}}(\rho, \theta) \\
 = & C_4(\rho^2 \cos 2\theta) + C_5(\rho^2 \sin 2\theta) \\
 10 & + C_{11}((4\rho^2 - 3)\rho^2 \cos 2\theta) \\
 & + C_{12}((4\rho^2 - 3)\rho^2 \sin 2\theta) + C_{16}(\rho^4 \cos 4\theta) \\
 & + C_{17}(\rho^4 \sin 4\theta) \dots \\
 & \dots \quad (4)
 \end{aligned}$$

[0017] When the root-mean-square value (RMS value) of the 15 wavefront aberration W of the equation (1) is denoted as r_w , the RMS value of the rotational symmetry component W_{rot} of the equation (2) is denoted as r_{rot} , the RMS value of the odd symmetry component W_{odd} of the equation (3) is denoted as r_{odd} , and the RMS value of the even symmetry 20 component W_{even} of the equation (4) is denoted as r_{even} , theses RMS values have the following relation.

$$(r_w)^2 = (r_{\text{rot}})^2 + (r_{\text{odd}})^2 + (r_{\text{even}})^2$$

[0018] Although it is obvious that r_{rot} has a correlation with a spherical aberration, the inventors of the present 25 invention have researched r_{odd} in relation to coma aberration and r_{even} in relation to astigmatism aberration, and as a result, have found that they have strong correlations. Accordingly, by using these three RMS

values r_{rot} , r_{odd} and r_{even} as evaluation indexes for a projection optical system, these RMS values can be related to the spherical, coma and astigmatism aberrations of the actual aerial image and resist image 5 formed by the projection optical system, and the projection optical system can be more rationally designed and adjusted.

[0019]

[Embodiment 1] Next, concrete examples of the evaluation 10 will be described by embodiments 1 and 2. In the embodiment 1, a relation between the RMS value r_{odd} of the odd symmetry component of the wavefront aberration and the coma aberration will be indicated. First, the quantification of the coma aberration will be described. 15 As methods of detecting the coma aberration using an aerial image and a resist image, various methods have long been known. The coma aberration causes a sideways shift of an image, and the quantity of the sideways shift is different depending on an object structure and a 20 spatial frequency. Therefore, the coma aberration can be quantified using the quantity of the sideways shift. Fig. 3 illustrates an example of an object structure (mask pattern) to detect the coma aberration. Five light shielding patterns each having a width L are arranged at 25 an interval S . In many cases, the interval S and the width L are same. When the interval S and the width L are equal, the object structure has two behaviors, i.e. a fine object on which lines each having the width L ($=S$)

are arranged at the interval S ad infinitum (an object having a high spatial frequency) and a big object having a width of $9S$ (an object having a low spatial frequency).

[0020] Next, an example of an adjusting method of the projection optical system will be described. When the rotational symmetry component of the wavefront aberration exists in the projection optical system, the rotational symmetry component of the wavefront aberration can be corrected by changing at least one interval out of a plurality of intervals between optical members that structure the projection optical system. When the odd symmetry component of the wavefront aberration exists in the projection optical system, the odd symmetry component and the coma aberration have a close correlation, and if the coma aberration is simple inner or outer coma aberration, the inner or outer coma aberration can be corrected by changing at least one interval out of the plurality of intervals between the optical members that structure the projection optical system. If the coma aberration is eccentric coma aberration (the coma aberration arisen because the optical members are eccentric or tilt with respect to an optical axis), the eccentric coma aberration can be corrected by moving at least one of the optical members in a direction perpendicular to the optical axis or tilting at least one of the optical members with respect to the optical axis.

[0021] Further, when the even symmetry component of the wavefront aberration exists in the projection optical

system, the even symmetry component and the astigmatism aberration have a close correlation, and if the astigmatism aberration arises due to simple field curvature, the even symmetry component can be corrected
5 by changing at least one interval out of the plurality of intervals between the optical members in the projection optical system. And, if the astigmatism aberration arises at a center of an image plane of the projection optical system (an axial astigmatism aberration), the even
10 symmetry component can be corrected by rotating at least one of the optical members in the projection optical system around the optical axis.

[0022] Figs. 4(a) and (4b) illustrate a light intensity distribution on the image plane in the case when an image
15 of the object is formed using the projection optical system. Fig. 4(a) shows the light intensity distribution without coma aberration, and Fig. 4(b) shows the light intensity distribution with coma aberration. When the light intensity distribution of Fig. 4 (b) is sliced at
20 the light intensity with which a light intensity width L_3 of a center line image among the five lines images becomes exactly $L \times m$ (m is a magnification of an optical system), and a light intensity width of an image of the leftmost line among the five lines is defined as L_1 and a
25 light intensity width of an image of the rightmost line is defined as L_5 , sizes of L_1 and L_5 are different. This is because the sideways shifts due to the coma aberration are different depending on the spatial frequency. Thus,

the coma aberration can be quantified utilizing the light intensity distribution, by defining, for example, coma aberration C as

$$C \equiv (L_1 - L_5) / (L_1 + L_5).$$

5 [0023] The inventors of the present invention have simulated the cases where the expanded coefficients C_1 , C_2 , $C_6 \dots$ of the odd symmetry component W_{odd} of the wavefront aberration in the equation (3) have various values, using Monte Carlo method, and have calculated the RMS value r_{odd} 10 of the odd symmetry component of the wavefront aberration and the coma aberration C in each case. The calculation conditions are as mentioned below.

N.A. of optical system (Numerical aperture): 0.60

Wavelength λ : 248.4nm

15 Magnification of projection optical system: 0.2

Object size L: 1.0 μm

(Width of center line image $L_3 = 0.2\mu\text{m}$)

Number of data: 500

[0024] Figs. 5(a) and (b) show a relation between the RMS 20 value r_{odd} of the odd symmetry component of the wavefront aberration and the coma aberration. Fig. 5(a) shows the case when a coherence factor (a ratio between NA of an illumination optical system and NA of a projection optical system) is 0.42, and Fig. 5(b) shows the case 25 when the coherence factor is 0.75. Error bars of a vertical axis show average values $\pm 1\sigma$. As clearly shown in these drawings, the inventors have confirmed that the RMS value r_{odd} of the odd symmetry component W_{odd} of the

wavefront aberration in the projection optical system has a strong correlation with the coma aberration.

[0025]

[Embodiment 2] Next, in the embodiment 2, a relation between the RMS value r_{evn} of the even symmetry component of the wavefront aberration and the astigmatism aberration will be described. In the same manner as the embodiment 1, the inventors have simulated the cases where the expanded coefficients C_4 , C_5 , C_{11} . . . of the even symmetry component W_{evn} of the wavefront aberration in the equation (4) have various values, using Monte Carlo method, and have calculated the RMS value r_{evn} of the even symmetry component of the wavefront aberration and the astigmatism aberration in each case. The calculation conditions are as mentioned below.

N.A. of optical system (Numerical aperture): 0.60

Wavelength λ : 248.4nm

Magnification of projection optical system: 0.2

Object shape: Pattern with infinite period

20 of $L = S = 1.0\mu m$
Number of data: 500

[0026]

Figs. 6(a) and (b) show a relation between the RMS value r_{evn} of the even symmetry component of the wavefront aberration and the astigmatism aberration. Fig. 6(a) shows the case when the coherence factor is 0.42, and Fig. 6(b) shows the case when the coherence factor is 0.75. Error bars of a vertical axis show average values $\pm 1\sigma$.

As clearly shown in these drawings, the inventors have confirmed that the RMS value r_{evn} of the even symmetry component W_{evn} of the wavefront aberration in the projection optical system has a strong correlation with 5 the astigmatism aberration. Note that the case is described above when an optical system of which the image forming quality is evaluated is a projection optical system of an exposure apparatus, however, the evaluating method of the present invention may be undoubtedly 10 applied to any types of image forming optical systems.

[0027]

[Effect of the Invention] As is described above, according to the present invention, by dividing wavefront aberration passing through an optical system into a 15 rotational symmetry component around a center of a pupil, an odd symmetry component and an even symmetry component, and performing the evaluation, these components can be related to spherical, coma and astigmatism aberrations of an actual aerial image and resist image formed by the 20 optical system, and thereby the optical system can be designed and adjusted more rationally.

[Brief Description of the Drawings]

Fig. 1 schematically illustrates an exposure apparatus used for manufacturing semiconductor devices and the like.

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Fig. 2 illustrates a conceptual diagram of wavefront aberration measurement by Fizeau interferometer.

Fig. 3 illustrates an example of an object structure
(mask pattern) for detecting coma aberration.

Fig. 4(a) illustrates a light intensity distribution on
5 an image plane when an image of the object in Fig. 3 is
formed by an optical system without the coma aberration,
and Fig. 4(b) illustrates a light intensity distribution
on the image plane when an image of the object is formed
by the optical system with the coma aberration.

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Fig. 5(a) illustrates a relation between a RMS value r_{odd}
of an odd symmetry component of wavefront aberration and
coma aberration C when a coherence factor is 0.42, and
Fig. 5(b) illustrates the relation when the coherence
15 factor is 0.75.

Fig. 6(a) illustrates a relation between a RMS value r_{even}
of an even symmetry component of the wavefront aberration
and astigmatism aberration when the coherence factor is
20 0.42, and Fig. 6(b) illustrates the relation when the
coherence factor is 0.75.

[References of Major Parts]

- | | |
|----------------------|---------------------------------|
| 11: Light source | 12: Illumination optical system |
| 25 13: Mask | 14: Projection optical system |
| 15: Wafer | 21: Light source |
| 22: Half prism | 23: Fizeau lens |
| 23a: Reference plane | 24: spherical mirror |

25: XY stage

26: Image pickup device

P: Pattern